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LIMNOLOGICAL CHARACTERISTICS OF NATURAL ACIDIC LAKES IN THE NORTH-WEST OF RUSSIA

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ABSTRACT. The results of investigations carried out on three natural acidic lakes of South Karelia are presented. The total lake mineralization was about 10 mg/L, Ca concentration — 0.16-0.46 mg/L, pH — 5.6-5.2, and Secchi disk transparency — 5-8 m over all growing season. The phytoplankton was represented by flagellate forms, cyanobacteria were completely absent, the diatom algae were scarce. The mean summer phytoplankton biomass was in the range 0.31-0.90 mg/L with maximum at the beginning of the summer. The maximum summer concentration of chlorophyll *a* did not exceed 2.4 μg/L, and the primary production was only 15-100 mgC/L per day. Abundance and biomass of bacteria varied in the range of $1.22\text{-}2.01 \cdot 10^6$ cell/L and 0.17-0.23 mg/L, the physiological activity of bacterioplankton was also low. In spite of low biomasses of phyto- and bacterioplankton, the abundances of zooplankton and zoobenthos were rather high. *Holopedium gibberum*, *Bosmina obtusirostris*, and *Diaphanosoma brachiurum* prevailed in the zooplankton at the absence of large planktonic predators (*Asplanchna*, *Leptodora*, *Bythotrephes*). The mean total zooplankton biomass during growing season was 1.44-4.45 g/m^3. Chironomids prevailed in the benthos, the leeches and molluscs were not found. The mean abundance of benthic animals in the lake littoral zone was 4785-7018 ind./m^2, and the biomass — 5.22-7.93 g/m^2. The density of bottom invertebrates in the profundal depended on the oxygen content in the bottom layer. The zoobenthos was absent under conditions of strong oxygen deficiency in hypolimnion; but in unstratified lakes the animal abundance and biomass were very high, 18766 ind./m^2 and 69.2 g/m^2, and the chironomid larvae were dominant forms. It is suggested that the major primary producers in acidic lakes are the mosses covering the lake bottom and the periphyton algae developing on the mosses. A possibility of using the natural acidic lakes to study the effect of anthropogenic acidification is discussed.

Key words: acidification, acidic lakes, plankton, benthos, trophic status of lakes.

1. Introduction

During the past 20 years, the attention of hydrobiologists has been attracted to the altering lake ecosystems under the influence of «acid» rains. The main reasons of anthropogenic acidification of small and medium lakes in the temperate zone are increasing soil acidity caused by the cessation of cattle grazing and subsequent changes in vegetation of drainage area (replacement of grasses by heathers and mosses, growth of trees), as well as increasing acidity of precipitations resulted from industrial pollution of the atmosphere (Groterud 1984). The emphasis in acidification studies is usually placed on chemical processes (especially at the water-bottom interface) and changes in plankton and benthos communities allowing to distinguish the indicator species. The peculiarities of the acidified lake functioning remain practically unstudied. In this connection, the natural acidic lakes are of particular interest because they can be considered as test areas for studying the effects of anthropogenic acidification.

According to the adopted classification (Abrosov 1982), natural acidic lakes are those whose entire geological history took place at pH less than 6.0. This is true for small lakes without outflow situated in the sandy soils of the North-West of Russia with very low quantity of $CaCO_3$ and, therefore, depleted in Ca ions (Steinberg 1988). In acidified waters the humic acids precipitate on the bottom bounding many cations and thus leading to an additional decrease in the total water mineralization. Specific drainage areas of the lakes are small; rain and snow being the main source of the water supply are practically devoid of salts; the total water mineralization usually does not exceed 10-15 mg/L. Trivalent metals (Fe, Al), precipitating on the bottom along with humic acids, remove mineral phosphorus from the biotic turnover. As a result, a low phosphorus content is observed in the acidic lake water while the sediments are enriched with P (according to data by L.I. Kalinina for acidic lakes of the Pskov region). Low pH and total mineralization values along with a high transparency due to precipitation of humic acids determine the peculiar conditions in the acidic lakes. The aim of the present work was to obtain an overall picture of structure and probable functional relations in the lakes with extremely low values of water pH.

2. General description of lakes. Methods of studies

The studies were carried out in Akkakharsky lakes situated in the south of Karelia, at the border with the Leningrad region. These lakes sharply differ in their limnological characteristics and include riverine mesotrophic lake Kostomojarvi, distrophic lakes Komarinoye and Splavinnoye, acidic transparent lakes Goluboe 1, Goluboe 2 and Shkolnoe. On the shore of the latter, a small suburban settlement is situated. Despite episodic character of observations a rather vast body of data collected over four years (1989-1992) allowes to evaluate some interesting peculiarities of limnology of natural acidic lakes.

All the three acidic lakes are situated among sandy hills overgrown with pine forest. The lake surface areas are as follows: Shkolnoe Lake — 4, Goluboe 1 — 5, and Goluboe 2 — 2 ha. Like all lakes of this type, they are relatively deep: the ratio of the lake area (in ha) to their maximum depths (in m) is about 0.17 while in Kostomojarvi lake it is 6.26. All the lakes have no visible inflow and outflow. The littoral zone is poorly pronounced and macrophytes are practically absent. Whereas there is no summer stratification in Goluboe 2 Lake (the oxygen concentration in the bottom layer achieves here 80-100%), a sharp stratification is observed in Goluboe 1 Lake: the depth of epilimnion is 5-6 m; the difference between surface and bottom temperature attains 10-12°C in July-August, and the oxygen concentration near bottom varying in the same time from 5 to 40% saturation. Shkolnoe Lake occupies an intermediate position because the hypolimnion is formed there not every year: in July-August 1989, the temperatures of surface and bottom layers differed by 6-8°C and the bottom layer oxygen saturation was 5.3-5.9 while in 1990, the temperature difference was only about 2°C and oxygen saturation near the bottom is 77.9-85.5%.

The water transparency determined with the Secchi disk was in the period of studies 4.0-6.2 m in Shkolnoe Lake, 5.0-7.0 m in Goluboe 1 Lake, and up to the bottom in Goluboe 2 Lake (the maximum depth about 8 m); the mean values for this period were 4.7, 6.0, and 8.0 m, respectively. The ratios of the lake maximum depth to the Secchi disk depth, characterizing the relative depth of the light penetration, are given in Table 1.

Hydrochemical characteristics were determined using standard methods. The active reaction of water varied in the summer within the range of 5.5-5.9 in Shkolnoe Lake, 5.3-5.6 in Goluboe 1 Lake, and 5.2-5.4 in Goluboe 2 Lake. The mean total carbon dioxide content was 1.44 mgC/L in the acidic lakes. The amount of ions was about 10 mg/L in all three lakes, the Ca concentration — 0.16-0.46 mg/L, and the Cl concentration — 2.03-2.13 mg/L.

Table 1. Relative water transparency, concentrations of chlorophyll *a*, particulate organic matter (POM) and seston, and photosynthesis rate at optimum depth (A_{opt}) and plankton respiration (R) on the average over the vegetation season (June-September). 1 — Goluboe 2 Lake, 2 — Goluboe 1, 3 — Shkolnoe, 4 — Kostomojarvi.

Characteristics	Lakes			
	1	2	3	4
Number of measurements	6	12	6	12
Relative transparency	1	1.50±0.24	1.65±0.39	5.75±0.80
Chlorophyll, μg/L	0.49±0.17	0.99±0.44	1.33C0.70	7.75±5.40
POM, mg/L	0.24±0.55	0.72±0.13	0.72±0.19	1.72±0.68
Seston, mg/L	1.02±0.22	1.28±0.27	1.34±0.30	4.23±1.28
A_{opt}, μgC/L per day	22±7	38±11	65±10	114±56
R, μgC/L per day	41±19	57±20	54±12	100±77

The concentration of mineral phosphorus was determined with standard chemical method (Golterman 1969) and with addition of various amounts of phosphate in combination with radiolabelled phosphoric acid. The latter method allows to estimate the concentration of biologically active mineral phosphorus. It was shown that content of mineral phosphorus in the water was rather low (0-5 μg/L), and only 20% of it was in biologically available form. The quantity of particulate organic matter (POM) estimated by bichromate oxidizability of suspension was on the average 0.72 in Shkolnoe Lake, 0.71 in Goluboe 1, and 0.55 mgC/L in Goluboe 2.

The primary production of plankton and microphytobenthos (with Winkler's oxygen method) as well as the chlorophyll concentration in the plankton, and the concentration of seston were measured. All these indices were obtained using standard methods.

Studies on bacterioplankton include: 1) evaluation of bacterioplankton density by direct counting on filters, and 2) evaluation of its physiological activity by means of such criteria as biochemical oxygen consumption (BOC), dark assimilation of carbon dioxide, and assimilation of labile dissolved organic matter using hydrolyzate of vegetational protein labelled with carbon.

The composition and distribution of planktonic and benthic animals were studied, and their abundance and biomass were evaluated.

3. Results

3.1. Phytoplankton

A peculiar species composition of algae is characteristic of the plankton of acidic lakes. During almost entire growing season, the flagellates prevail in the plankton; mobility of these forms may be an important feature allowing them to migrate using good light conditions of the epilimnion and higher concentrations of nutrients in thermocline zone and hypolimnion. In spring the phytoplankton is represented by a practically monodominant community. The biomass (biovolume) was rather high (about 2 mg/L) and diversity index calculated for relative biomasses according to Shannon formula was the lowest (0.15-0.28 bit). The dinophyte algae *Peridinium inconspicuum* Lemm. and small (3-6 μm) unidentified flagellates prevailed in this period. In summer, the biomass decreased to 0.14-0.77 mg/L (Table 2), whereas the diversity increased up to 1.22-1.76 bit. The crysophytes of the genus *Dinobryon* (*D. pediforme* (Lemm.)) Steinecke prevailed in Goluboe 2 whereas *D. divergens* Imh. was dominant in Goluboe 1. In the summer plankton the chlorococcal algae *Oocystis lacustris* Chodat and *O. submarina* which are typical of acidic oligotrophic lakes (Trifonova 1990, Ilmavirta 1984) were also found. By autumn, when total biomass was 0.12-0.29 mg/L the dominant forms were dinophyte algae *Glenodinium*, *Peridinium*, and *Amphidinium*. The average phyto-

Table 2. Dynamics of total biomass and the percentage of certain groups of algae in the plankton of acidic lakes in summer 1991. Dashes indicate the absence of data.

Algae	Dates					
	1.06	21.06	15.07	3.08	18.08	20.09
Goluboe 1 Lake						
Blue-greens	0.00	4.10	0.00	—	0.00	0.00
Diatoms	0.00	1.80	0.00	—	0.50	10.20
Dinophyta	97.6	56.20	35.7	—	69.80	53.60
Cryptophyta	0.30	2.50	3.70	—	0.00	0.00
Greens	0.00	1.70	0.00	—	0.00	0.00
Yellow-greens	1.80	33.7	60.6	—	29.70	36.20
Total biomass, mg/L	1.79	0.84	1.07	—	0.49	0.29
Goluboe 2 lake						
Diatoms	0.00	0.80	1.40	0.00	17.30	0.00
Dinophyta	98.0	51.50	7.00	0.00	0.00	13.70
Cryptophyta	0.00	0.00	7.50	4.10	0.00	0.00
Greens	0.40	12.6	32.4	30.0	17.30	41.80
Chrysophyta	0.40	30.80	33.9	33.1	57.90	36.00
Euglenophyta	1.10	4.30	17.6	32.3	7.50	8.00
Total biomass, mg/L	1.18	0.23	0.14	0.06	0.13	0.12

plankton biomass over the growing season was in the range 0.90±0.65 mg/L for Goluboe 1 Lake and 0.31±0.44 mg/L for Goluboe 2 Lake.

The data on the phytoplankton biomass were confirmed by measurements of chlorophyll *a* concentration. In Shkolnoe Lake, the chlorophyll content in summer months varied from 0.62 to 2.4, in Goluboe 1 Lake — from 0.37 to 1.8, and in Goluboe 2 — from 0.33 to 0.76 μg/L (Table 1).

The maximum rate of photosynthesis (A_{opt}) in Shkolnoe Lake achieved 50-100 gC/L per day (according to data of 1989 and 1991); whereas in Goluboe 2 in 1991 it was even lower — 15-50 μgC/L per day (Table 1).

3.2. *Phytobenthos*

The phytobenthos was studied in most detail in Goluboe 1 Lake in 1991. The species composition, the biomass of some groups of algae, and the rate of photosynthesis in the offshore zone at the depth of 1 m were studied. By the biomass value, desmidian algae (species of genera *Penium*, *Euastrum*, *Hyalotheca*) and green algae (*Oedogonium* spp., *Chlorospira crassa* Korsch., *Microspora* sp.) dominated in the phytobenthos. Diatom algae occurred in small amount, their share in the total biomass did not exceed 25% and was 15% on the average over the period from late June to early August. The phytobenthos biomass increased during summer from 13.8 mg

Table 3. Seasonal dynamics of abundance and biomass of planktonic bacteria in acidic lakes in summer 1991. N — abundance, 10^6 cell/ml. B — biomass, mg/L.

Lake	Date	N	B
Goluboe 1	1.06	1.03	0.18
	21.06	1.23	0.23
	16.07	1.23	0.13
	2.08	1.09	0.17
	22.08	0.88	0.15
	20.09	1.73	0.21
Goluboe 2	1.06	0.86	0.15
	21.06	1.13	0.22
	16.07	2.14	0.38
	2.08	1.18	0.19
	22.08	0.92	0.17
	20.09	1.57	0.24

Table 4. Heterotrophic activity of planktonic microflora in lakes of Akkakhara group. B_b — biomass, P_b — production calculated with the method by Romanenko (1964), A_b — assimilation of bacteria, RSOM (BOC 5) — readily soluble organic matter. All indices in μgC/L, the production and biomass are calculated per day. Dashes indicate the absence of data.

Lakes	Date	B_b	RSOM	P_b	A_b	P_b/A_b	A_b/B_b	A_b/RSOM
Goluboe 2	21.06.91	22	240	14	131	0.6	6.0	54
Goluboe 1	12.07.90	9	610	59	42	6.5	4.7	7
	14.09.90	18	200	17	16	1.0	0.9	8
	21.06.91	37	350	42	139	1.1	3.7	40
	20.09.91	4	100	24	5	6.0	1.3	5
Shkolnoe	12.07.90	34	350	68	62	2.0	1.8	18
	12.09.90	26	300	—	20	—	0.8	7
Kostomojarvi	12.07.90	37	800	135	120	3.6	3.2	15
	12.09.90	29	1050	18	85	0.6	2.9	8
	22.06.91	29	135	79	105	2.7	3.6	78
	28.07.91	82	934	184	212	2.2	2.6	23
	20.09.91	46	550	32	134	0.7	2.9	62

per dm^2 of bottom surface at the end of June to 33.5 in the second half of August. The productivity of phytobenthos also increased from 0.1 to 1.63 mgO/dm^2 (3.3-54 mgC/m^2). At the beginning of the season the productivity of phytoplankton in the littoral zone was three times as higher than that of phytobenthos but phytobenthos produced 1.6 times as more of organic carbon than phytoplankton.

Thus, owing to the light regime and the phosphorus precipitation, the conditions are formed for the development of bottom vegetation. The carpet of mosses, abundant filamentous algae and periphyton are especially characteristic of all acidic lakes, including those which are considered in present study.

3.3. Bacterioplankton

The most part of bacteria was represented by small cells with prevailing cocci about 0.35 μm in diameter. Abundance of small bacilli (0.4 × 1.8 μm) was much lower. Larger cocci (0.9 m in diameter) and bacilli (0.9 × 2.2 μm) occurred in smaller numbers. During the growing season, the number and biomass of planktonic bacteria varied within a narrow range (Table 3). The year-to-year differences in quantitative development of bacterioplankton were also weakly pronounced; on the average, the abundance and biomass were 1.22±0.36 and 0.17±0.06 in Goluboe 1 Lake, 1.30±0.51 and 0.23±0.09 in Goluboe 2, and 2.01±0.80 10^6 cell/mL and 0.19±0.10 mg/L in Shkolnoe respectively.

The data on physiological activity of bacteria in acidic lakes and in mesotrophic lake Kostomojarvi are summarized in Table 4. As it is seen from the table, the highest activity of bacterioplankton in acidic lakes was observed at the beginning of summer while in the mesotrophic lake an increase was recorded at the end of the season. This is probably connected with the above-considered spring development of phytoplankton in the acidic lakes.

3.4. Zooplankton

The pH value strongly influence the species composition of zooplankton community in acidic lakes. According to classification by Salazkin

Table 5. Total biomass of mesozooplankton and the percentage of individual zooplankters in Goluboe 1 and 2 Lakes in 1991.

Species or group of species	Day, month					
	31.05	21.6	13.7	2.8	19.8	20.9
Goluboe 1 Lake						
B. obtusirostris	19.10	14.00	22.50	1.90	1.90	3.20
H. gibberum	5.70	3.10	16.70	0.90	1.40	2.80
C. quadrangula	3.60	3.40	37.20	48.60	5.00	22.80
D. brachiurum	0.40	1.30	3.00	19.70	77,40	28.10
Chydoridae	<0.10	<0.10	1.90	0.40	0.00	<0.10
P. pediculus	0.00	0.00	0.40	<0.10	1.00	0.10
M. leuckarti + C. scutifer	71.20	78.10	16.70	27.80	12.70	40.20
A. denticornis	0.00	0.10	1.40	0.50	0.70	2.80
H. appendiculata	0.00	0.00	0.00	<0.10	0.00	0.00
Daphnia sp.	0.00	<0.10	0.10	<0.10	0.00	0.00
Total biomass, g/m^3	0.16	0.89	1.63	1.44	3.51	1.25
Goluboe 2 Lake						
B. obtusirostris	16.80	3.40	33.60	12.70	7.00	5.10
H. gibberum	64.40	94.70	60.20	10.60	0.00	0.00
C. quadrangula	0.00	0.70	0.00	0.00	0.30	1.00
D. brachiurum	0.40	<0.10	3.70	62.80	65.30	18.50
Chydoridae	0.20	<0.10	0.20	0.00	0.00	<0.10
P. pediculus	0.00	0.10	0.20	0.40	0.20	0.60
M. leuckarti + C. scutifer	18.10	0.20	0.40	0.30	1.30	0.20
A.denticornis	0.20	0.70	1.60	13.10	25.90	74.50
Total biomass, g/m^3	0.41	1.98	4.92	3.84	2.10	2.66

(1976), the Karelian lakes may be divided into oligoacidic (Shkolnoe) and mesoacidic (Goluboe 1 and 2) by the value of water active reaction. According to published data, the pelagic zooplankton of oligoacidic lakes is represented by *Eudiaptomus graciloides* (Lill.), *Mesocyclops leuckarti* (Claus), *Diaphanosoma brachiurum* (Liev.), *Asplanchna* sp., *Daphnia cristata* Sars, *Holopedium gibberum* Zaddach, *Bosmina obtusirostris* Sars. This is precisely the complex of species which was found in the plankton of Shkolnoe lake where the dominant species was *H. gibberum* and the subdominants were *B. obtusirostris* and *Cyclops scutifer* Sars. In mesoacidic Goluboe 1 Lake in 1989 and 1990 the abundance of cladoceran and copepod crustaceans was much the same during the season, *H. gibberum, B. obtusirostris*, and *D. brachiurum* prevailed among Cladocera, the copepods were represented by two species, *C. scutifer* and *Acanthodiaptomus denticornis* (Wierzeiski), with dominating *C. scutifer*. In 1991 *C. scutifer* dominated during almost the entire growing season; only at the end of August and in September *D. brachiurum* and *Ceriodaphnia quadrangula* (O.F. Muller) prevailed (Table 5). In pelagic zooplankton of Goluboe 2 Lake, cladocerans prevailed during the entire season, the dominants were *D. brachiurum* and *H. gibberum*. For all three acidic lakes, one may mention the absence of rotifers of the genus *Asplanchna*. The data on abundance and biomass of zooplankton are given in Table 6. The diversity values were rather low, similar to those of phytoplankton (Fig. 1). It should be mentioned that the low value of diversity index in these lakes is explained with the sharp dominance of a certain species rather than with the small number of species. Overall, 22 species of planktonic crustaceans have been found in the plankton of the lakes; they included 15 species of Cladocera and 7 species of Copepoda.

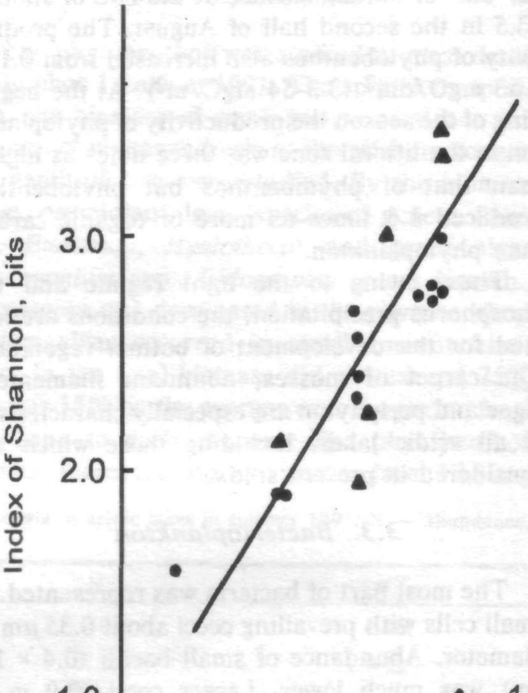

Fig. 1. Dependence of Shannon's diversity index on the pH value in Akkakharju lakes by observations in 1989-1992. 1 — phytoplankton, 2 — zooplankton.

The most complete data on seasonal dynamics of abundance and biomass of the zooplankton were obtained for Goluboe 1 and Goluboe 2 lakes (Table 5). The absence of drastic ups and downs in total biomass is presumably connected with dominance of two or three species during the most part of growing season.

3.5. Zoobenthos

The zoobenthos was studied in 1991. Overall, 59 species have been found in the benthos of Goluboe 1 Lake and 70 species in Goluboe 2. Such groups of macrozoobenthos as molluscs and leeches were completely absent; this was probably connected with increased sensitivity of these animals to acidity of the environment (Eriksson et al. 1974, Minns and Moore 1990). Chironomid larvae were the dominating group in littoral communities of macrozoobenthos. In the littoral of Goluboe 1 Lake the average values of biomass

Table 6. Mean biomasses of mesozooplankton over the summer season in acidic lakes, g/m³. Dashes indicate the absence of data.

Lake	Year			
	1989	1990	1991	1992 (August-September)
Shkolnoe	1.44±1.21	1.63±1.02	—	—
Goluboe 1	1.17±0.66	3.30±1.25	1.74±1.13	4.11±0.78
Goluboe 2	—	4.45±1.66	3.23±1.26	2.50±2.16

over the season equal to 7.93±1.31 g/m^2 and abundance of 7018±1234 ind./m^2, the biomass and abundance of chironomids comprised 4.90±0.85 g/m^2 and 5525±987 ind./m^2. In the littoral communities of Goluboe 2 Lake, the total benthos biomass over the season achieved 5.22±1.59 g/m^2 at the abundance of 4785·10^3 ind./m^2, while the respective values for chironomids were 3.376±0.69 g/m^2 and 4040±742 ind./m^2. The littoral communities of the lakes were similar in their structure; there were no sharply dominating species.

The profundal bottom fauna of acidic lakes often contains species which are more characteristic of the littoral in other lakes than of the profundal (Dermott 1985). An analysis of the profundal species composition in Goluboe 2 lake has confirmed this statement. At the depth of 7.5 m where the water was transparent to the bottom, the profundal of this lake was covered with layer of mosses, and the water near bottom layer was rich in oxygen.

Like in the littoral, the chironomid larvae (e.g. *Corynoneura scutellata* Winner, *Oxyethira costalis* (Curtis), *Psectrocladius* spp.) prevailed in the profundal of this lake though the oligochaetes of the genus *Vejdovskiella — V. comata* (Vejdovski) and *V. macrochaeta* (Lastochkin) were also common. On average the values of total macrobenthos biomass and abundance were 69.20±31.47 g/m^2 and 18766±4068 ind./m^2, the chironomid larvae achieved 68.10±31.50 g/m^2 and 17076±4125 ind./m^2, respectively. The main bulk of biomass was formed by *Chironomus dorsalis* Meigen and *Einfeldia pagana* (Meigen). In the profundal of Goluboe 1 lake, the zoobenthos was practically absent probably because of oxygen deficiency in the bottom layer of water.

4. Discussion

The species composition of acidic lakes communities is evidently determined by the value of the water active reaction. All species of plankton and benthos found in the lakes studied are common in lakes with pH less than 6.0 (Salazkin 1976, Lazareva 1992).

The following peculiarities of the species structure of benthic and pelagic communities can be recognized as typical of weakly mineralized acidic lakes. In the phytoplankton and microphytobenthos there are no blue-greens, and the diatoms are rather scarce. Flagellate forms prevail in the phytoplankton, while filamentous greens dominate in the microphytobenthos. Obligatorily predatory invertebrates are virtually absent: there are no such common for lakes of the North-West animals as leeches, *Chaoborus* larvae, predatory planktonic crustaceans (*Leptodora kindti* and *Bythotrephes longimanus*). The fish in acidic lakes are either represented by 1-2 scarce species or they are completely absent. Thus the effect of predator pressure on the development of herbivores is minimum.

The acidic lakes in fact hardly can be assigned to a certain trophic class within the frameworks of traditional system. Indeed, if one uses the trophic scale developed on lakes of the North-West of Russia (Kitaev 1984), all the three lakes studied can be considered as oligotrophic by the values of POM and chlorophyll *a* concentration. At the same time, according to the biomass of mesozooplankton and mesobenthos these lakes can be characterized as mesotrophic-eutrophic. Especially high values of animal biomass were observed in Goluboe 2 Lake which is similar to polytrophic lakes by the abundance of profundal mesobenthos, while is the least productive by phytoplankton. Disturbance of usual proportions between planktonic producers and consumers is a characteristic feature of lakes with pH less than 6.0 and with high water transparency. For instance, in the best studied acidic lake Okhotnichje, the mean biomass of phytoplankton over the growing season did not exceed 0.4 g/m^3 while the biomass of mesozooplankton was equal to 1.4-1.5 g/m^3 (Osobennosti formirovanija kachestva vod... 1984). In acidic lakes of the taiga zone of the Kola Peninsula, these values were equal to

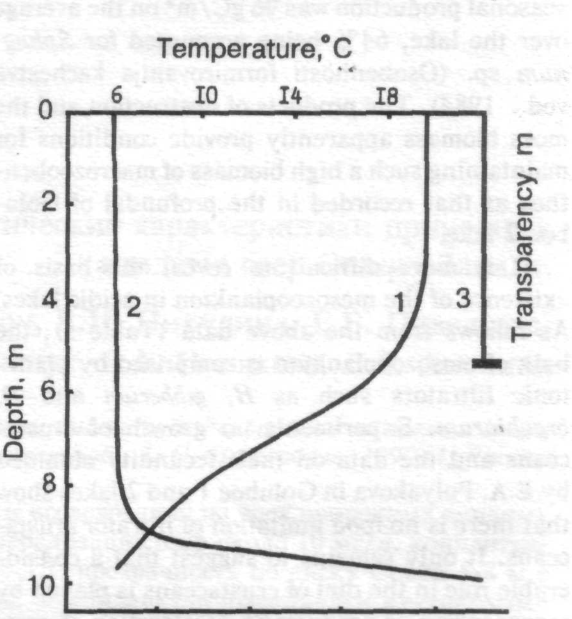

Fig. 2. Vertical distribution of temperature (1), turbidity (2), and the Secchi disk water transparency (3) in Shkolnoe Lake on 12.09.1992.

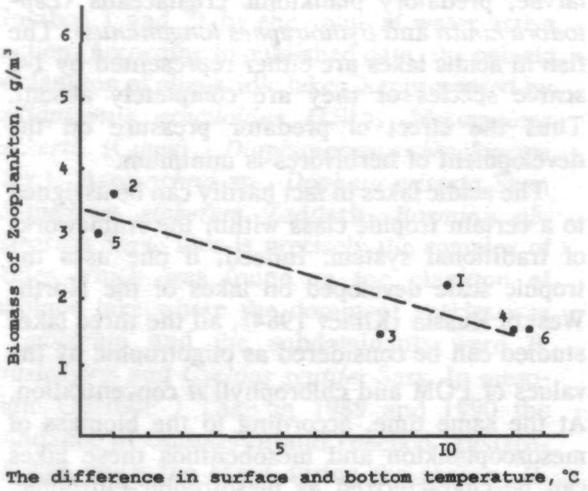

Fig. 3. Relationship between the mesozooplankton biomass and the difference between surface and bottom temperatures in July. 1 — Goluboe 1 Lake, 2 — Goluboe 2, 3 — Shkolnoe, 4 — Okhotnichje, 5 — Valgjarvi, 6 — Vitalampa.

0.05 and 0.7 cal/L respectively (Drabkova and Sorokin 1979). It is obvious that even in the absence of predators nutritional conditions are important to maintain the animal populations. As it has already been mentioned above, the bottom of acidic lakes is covered with mosses (mostly *Sphagnum* sp.) which create a large portion of total primary production in such lakes. In Okhotnichje lake, the phytoplankton seasonal production was 22-24 gC/m^2 while the macrophyte seasonal production was 96 gC/m^2 on the average over the lake, 64% being accounted for *Sphagnum* sp. (Osobennosti formirovanija kachestva vod... 1984). The products of destruction and the moss biomass apparently provide conditions for maintaining such a high biomass of macrozoobenthos as that recorded in the profundal of Goluboe 2 lake.

It is more difficult to reveal the basis of existence of the mesozooplankton in acidic lakes. As follows from the above data (Table 5), the bulk of mesozooplankton is comprised by planktonic filtrators such as *H. gibberum* and *D. brachiurum*. Experiments on growth of crustaceans and the data on their fecundity obtained by E.A. Polyakova in Goluboe 1 and 2 lakes show that there is no food limitation of filtrator crustaceans. It only remains to suggest that a considerable role in the diet of crustaceans is played by resuspension of products of desctruction of mosses and periphyton algae. It is also possible that the development of small flagellates, which can be used as food, takes place in the bottom water layer. Observations in Shkolnoe Lake (Fig. 2) indicate that an aggregation of POM occurs near the bottom. A sharp increase was found in the concentration of seston and chlorophyll *a* near the bottom; at the same time, no increase in phytoplankton concentration was observed in simultaneously collected samples. It is probable that this mass of suspended material was formed by nanoplanktonic species. An indirect evidence for connection between the development of mesozooplankton and the availability of food in the bottom layer may be the fact that the zooplankton biomass is smaller in acidic lakes with well-expressed hypolimnion and, accordingly, stable hypolimnial deficiency of oxygen. In seems likely that formation of cold oxygen-free zone isolates in some way a considerable part of the bottom layer. The dependence of the zooplankton biomass at the end of July on the difference in water temperatures between surface and bottom layers is presented in Fig. 3. Such a difference in temperatures may serve as an index of summer stratification of the lake water mass. The biomass of zooplankton at the end of July is taken because just in this time it usually peaks in the lakes of North-Western region of Russia. The data are plotted for the zooplankton of the three lakes studied as well as of Valgjarvi lake (Estonia) (Antropogennoe vozdeistvie na malye ozera 1980) and Vitalampa lake (Sweden) (Eriksson et al. 1974).

Reasoning from the above-said, it can be suggested that the main energy flow in acidic lakes passes through the bottom communities. Hence it follows that a particular emphasis should be placed upon the study of processes at the bottom-water boundary when investigating the acidic lakes.

Comparison of the results of studying natural acidic lakes with the data on the community structure in lakes subjected to anthropogenic acidification (Brett 1989, Schindler et al. 1989) shows a complete identity of species composition. As a consequence of artificial acidification of lakes, the disappearance of species sensitive to lowered pH (fish in the first turn), the shortening of trophic chains, and the decrease in species diversity were observed in all water bodies studied (Muniz 1981, Roff and Kwiatkowski 1977, Henrikson et al. 1984, Schindler 1990). Therefore natural acidic lakes can be considered as a testing area for studying the effects of anthropogenic acidification.

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Лимнологические характеристики природных ацидных озер Северо-Запада.

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РЕЗЮМЕ. Приведены результаты исследований на трех природных ацидных озерах на юге Карелии. Общая минерализация озер около 10 мг/л, концентрация Ca 0.16-0.46 мг/л, pH воды 5.6-5.2, прозрачность по диску Секки 5-8 м в течение всего вегетационного сезона. Фитопланктон представлен жгутиковыми формами, синезеленые водоросли отсутствуют полностью, диатомовые развиты очень слабо. Биомасса фитопланктона в среднем за лето 0.31-0.90 мг/л, максимум отмечен в начале лета. Средняя летняя концентрация хлорофилла *a* не превышает 2.4 мкг/л, первичная продукция всего 15-100 мгС/л в сутки. Численность и биомасса бактерий в пределах 1.22-2.01 млн. клеток/л и 0.17-0.23 мг/л. Физиологическая активность бактериопланктона также мала. Несмотря на незначительные биомассы фито- и бактериопланктона численность